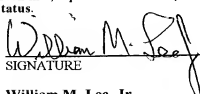


FORM PTO-1500 (Modified) (REV 11/2000)		U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE		ATTORNEY'S DOCKET NUMBER 721-1001	
TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371				U.S. APPLICATION NO. (IF KNOWN, SEE 37 CFR 1.5) 10/049886	
INTERNATIONAL APPLICATION NO PCT/IB00/01237		INTERNATIONAL FILING DATE September 1, 2000		PRIORITY DATE CLAIMED September 21, 1999	
TITLE OF INVENTION Stabilized Laser Source					
APPLICANT(S) FOR DO/EO/US Stefan Mohrdick					
Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information.					
<ol style="list-style-type: none"> 1. <input checked="" type="checkbox"/> This is a FIRST submission of items concerning a filing under 35 U.S.C. 371 2. <input type="checkbox"/> This is a SECOND or SUBSEQUENT submission of items concerning a filing under 35 U.S.C. 371. 3. <input type="checkbox"/> This is an express request to begin national examination procedures (35 U.S.C. 371(f)). The submission must include items (5), (6), (9) and (24) indicated below. 4. <input checked="" type="checkbox"/> The US has been elected by the expiration of 19 months from the priority date (Article 31) 5. <input checked="" type="checkbox"/> A copy of the International Application as filed (35 U.S.C. 371 (c) (2)) <ol style="list-style-type: none"> a. <input type="checkbox"/> is attached hereto (required only if not communicated by the International Bureau) b. <input checked="" type="checkbox"/> has been communicated by the International Bureau. c. <input type="checkbox"/> is not required, as the application was filed in the United States Receiving Office (RO/US). 6. <input type="checkbox"/> An English language translation of the International Application as filed (35 U.S.C. 371(c)(2)). <ol style="list-style-type: none"> a. <input type="checkbox"/> is attached hereto b. <input type="checkbox"/> has been previously submitted under 35 U.S.C. 154(d)(4). 7. <input checked="" type="checkbox"/> Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371 (c)(3)) <ol style="list-style-type: none"> a. <input type="checkbox"/> are attached hereto (required only if not communicated by the International Bureau). b. <input type="checkbox"/> have been communicated by the International Bureau c. <input type="checkbox"/> have not been made; however, the time limit for making such amendments has NOT expired. d. <input checked="" type="checkbox"/> have not been made and will not be made. 8. <input type="checkbox"/> An English language translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)) 9. <input type="checkbox"/> An oath or declaration of the inventor(s) (35 U.S.C. 371 (c)(4)). 10. <input type="checkbox"/> An English language translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371 (c)(5)). 11. <input type="checkbox"/> A copy of the International Preliminary Examination Report (PCT/IPEA/409). 12. <input type="checkbox"/> A copy of the International Search Report (PCT/ISA/210). 					
Items 13 to 20 below concern document(s) or information included:					
<ol style="list-style-type: none"> 13. <input type="checkbox"/> An Information Disclosure Statement under 37 CFR 1.97 and 1.98. 14. <input type="checkbox"/> An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included 15. <input checked="" type="checkbox"/> A FIRST preliminary amendment. 16. <input type="checkbox"/> A SECOND or SUBSEQUENT preliminary amendment. 17. <input type="checkbox"/> A substitute specification 18. <input type="checkbox"/> A change of power of attorney and/or address letter. 19. <input type="checkbox"/> A computer-readable form of the sequence listing in accordance with PCT Rule 13ter 2 and 35 U.S.C. 1 821 - 1 825 20. <input type="checkbox"/> A second copy of the published international application under 35 U.S.C. 154(d)(4) 21. <input type="checkbox"/> A second copy of the English language translation of the international application under 35 U.S.C. 154(d)(4). 22. <input type="checkbox"/> Certificate of Mailing by Express Mail 23. <input type="checkbox"/> Other items or information 					

U.S. APPLICATION NO. (IF KNOWN SEE 37 CFR 1.5) 10/049886		INTERNATIONAL APPLICATION NO. PCT/IB00/01237		ATTORNEY'S DOCKET NUMBER 721-1001					
24. The following fees are submitted: BASIC NATIONAL FEE (37 CFR 1.492 (a) (1) - (5)) : <input type="checkbox"/> Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO \$1040.00 <input checked="" type="checkbox"/> International preliminary examination fee (37 CFR 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO \$890.00 <input type="checkbox"/> International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.445(a)(2)) paid to USPTO \$740.00 <input type="checkbox"/> International preliminary examination fee (37 CFR 1.482) paid to USPTO but all claims did not satisfy provisions of PCT Article 33(1)-(4) \$710.00 <input type="checkbox"/> International preliminary examination fee (37 CFR 1.482) paid to USPTO and all claims satisfied provisions of PCT Article 33(1)-(4) \$100.00 ENTER APPROPRIATE BASIC FEE AMOUNT =				CALCULATIONS PTO USE ONLY <table border="1" style="width:100%; border-collapse: collapse;"> <tr> <td style="width:50%;">\$890.00</td> <td style="width:50%;"></td> </tr> <tr> <td>\$0.00</td> <td></td> </tr> </table>		\$890.00		\$0.00	
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Surcharge of \$130.00 for furnishing the oath or declaration later than _____ <input type="checkbox"/> 20 <input type="checkbox"/> 30 months from the earliest claimed priority date (37 CFR 1.492 (e)).				<table border="1" style="width:100%; border-collapse: collapse;"> <tr> <td style="width:50%;"></td> <td style="width:50%; text-align: center;">\$0.00</td> </tr> </table>			\$0.00		
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CLAIMS		NUMBER FILED	NUMBER EXTRA	RATE					
Total claims		11 - 20 =	0	x \$18.00	\$0.00				
Independent claims		2 - 3 =	0	x \$84.00	\$0.00				
Multiple Dependent Claims (check if applicable) <input type="checkbox"/>					\$0.00				
TOTAL OF ABOVE CALCULATIONS =					\$890.00				
<input type="checkbox"/> Applicant claims small entity status See 37 CFR 1.27) The fees indicated above are reduced by 1/2.					\$0.00				
SUBTOTAL =					\$890.00				
Processing fee of \$130.00 for furnishing the English translation later than _____ <input type="checkbox"/> 20 <input type="checkbox"/> 30 months from the earliest claimed priority date (37 CFR 1.492 (f)).				+	\$0.00				
TOTAL NATIONAL FEE =					\$890.00				
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31) (check if applicable).				<input type="checkbox"/>	\$0.00				
TOTAL FEES ENCLOSED =					\$890.00				
					Amount to be: refunded	\$			
					charged	\$			
a. <input checked="" type="checkbox"/> A check in the amount of \$890.00 to cover the above fees is enclosed b. <input type="checkbox"/> Please charge my Deposit Account No. _____ in the amount of _____ to cover the above fees. A duplicate copy of this sheet is enclosed c. <input checked="" type="checkbox"/> The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No 12-0913 A duplicate copy of this sheet is enclosed. d. <input type="checkbox"/> Fees are to be charged to a credit card. WARNING: Information on this form may become public. Credit card information should not be included on this form. Provide credit card information and authorization on PTO-2038									
NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.									
SEND ALL CORRESPONDENCE TO.									
William M. Lee, Jr. Lee, Mann, Smith, McWilliams, Sweeney & Ohlson P.O. Box 2786 Chicago, Illinois 60690-2786									
					SIGNATURE  William M. Lee, Jr. NAME 26,935 REGISTRATION NUMBER February 13, 2002 DATE				

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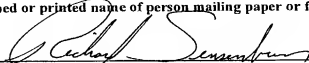
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Date of deposit: February 13, 2002

I hereby certify that this paper or fee is being deposited with the United States Postal Service "Express Mail Post Office to Addressee" service under 37 CFR 1.10 on the date indicated above and is addressed to the Assistant Commissioner for Patents, Washington DC 20231

Richard Sensenbrenner

(Typed or printed name of person mailing paper or fee)



(Signature of person mailing paper or fee)

721-1001

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

IN RE THE APPLICATION OF)
)
Stefan Mohrdiek)
)
)
SERIAL NO.: To Be Assigned)
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FILED: Herewith)
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FOR: Stabilized Laser Source)

AMENDMENT ACCOMPANYING APPLICATION

Honorable Director of Patents
and Trademarks
Washington, D.C. 20231

Dear Sir:

The present application is the national filing of International Application No. PCT/IB00/01237. Before calculation of the national filing fee for the United States, it is requested that the application be amended as follows:

In the Claims

Cancel claims 1-11 without prejudice, and substitute respective new claims 12-22 as follows:

12. A laser source for generating a stable laser beam of a given bandwidth, including a laser and guide means for conducting the laser beam exiting said front facet, comprising

- a plurality of external cavities at least partly within or as part of said laser beam guide means, each of said cavities being established by at least two reflectors,
- said plurality of external cavities being dimensioned and arranged such that said laser operates essentially in a coherence collapse mode.

13. The laser source according to claim 12, wherein

- all cavities are situated within the laser beam guide means, preferably in front of the laser.

14. The laser source according to claim 12, wherein

- one or more cavities are arranged within the laser beam guide means in front of the laser,
and
- at least one cavity is arranged at the rear of the laser.

15. The laser source according to claim 12, including in combination

- a "serial" cavity arranged within the laser beam guide means,
- a "lateral" cavity arranged outside said laser beam guide means, and
- a beam splitter/combiner deflecting a portion of the beam into said lateral cavity.

16. The laser source according to claim 12, wherein

- two reflectors, in particular Bragg gratings, are provided, whose peak wavelengths are offset and/or bandwidths are different.

17. The laser source according to claim 12, wherein

- the laser emits light between 800 and 1600nm and/or
- any of the reflectors or beam splitters/combiners has a reflectivity maximum within the bandwidth of the laser, and/or
- a bandwidth of its reflectivity between 0.05 and 2nm full-width half-maximum, and/or
- a peak reflectivity between 0.005 and 0.4.

18. The laser source according to claim 12, wherein

- the optical field established in the first cavity is out of phase with the optical field of the laser, and
- the optical field established in the second cavity is out of phase with the optical field established in said first cavity,
- thus inhibiting phase matching with the laser and hence coherent operation of said laser source.

19. The laser source according to claim 12, wherein

- the laser is a semiconductor diode laser, especially an InGaAs quantum well diode laser, and/or
- the laser guide means comprises an optical fiber, either a polarization-maintaining or non-polarization maintaining optical fiber, and/or
- the reflectors are fiber Bragg gratings within said fiber.

20. The laser source according to claim 12, further comprising

- means for directing the laser beam into the optical fiber, in particular beam collimating or focusing means attached to or integrated into said optical fiber.

21. A method of making a laser source that generates a stable laser beam of a given bandwidth, said laser source having a laser and laser beam guide means in front of said laser, comprising the steps of

- simultaneously manufacturing, preferably within said laser beam guide means, a plurality

of reflectors, which form, together with the laser front facet, the desired external cavities in front of said laser.

22. The method of making a laser source according to claim 21, whereby
- the simultaneous manufacturing is carried out by UV exposure methods creating the reflectors as fiber Bragg gratings in the optical fiber constituting the laser beam guide means

REMARKS

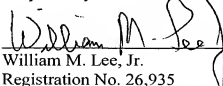
The above amendments are being made in order to eliminate multiple dependency and improper multiple dependency before calculation of the national filing fee for the United States. Should any multiple dependency remain, that is unintended, and the Patent and Trademark Office is requested to cancel any remaining multiple dependent claims without prejudice before calculation of the filing fee.

The International Preliminary Examination Report reaches the conclusion that the claims meet the requirements of novelty and inventive step (non-obviousness). The claims of the present application correspond exactly to the claims of the international application, except that specification references have been deleted. It is therefore submitted that the same result as in the international application should occur in the present application.

Examination of the application on its merits is awaited.

February 13, 2002

Respectfully submitted,



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Description**Stabilized Laser Source****5 Field of the Invention**

The invention relates to the stabilization of a laser, specifically a semiconductor diode laser of the type commonly used in opto-electronics, mostly as so-called pump lasers for fiber amplifiers in the field of optical communication, e.g. for Erbium-doped fiber amplifiers. Such lasers are designed to provide a
10 narrow-bandwidth optical radiation with a stable power output in a given frequency band. In particular, the invention concerns an improved design of the external cavity exhibiting a significantly improved stability compared to prior art designs.

15 Background and Prior Art

Semiconductor lasers of the type mentioned above have, for example, become important components in the technology of optical communication, particularly because such lasers can be used for amplifying optical signals immediately by optical means. This allows to design all-optical fiber commu-
20 nication systems, avoiding any complicated conversion of the signals to be transmitted which improves speed as well as reliability within such systems.

In one kind of optical fiber communication systems, the lasers are used for pumping Erbium-doped fiber amplifiers, so-called EDFAs, which have been
25 described in various patents and publications known to the person skilled in the art. An example of some technical significance are 980nm lasers with a power output of 150mW or more, which wavelength matches the 980nm Erbium absorption line and thus achieves a low-noise amplification. InGaAs lasers have been found to serve this purpose well and are used today in significant numbers. However, the invention is in no way limited to InGaAs la-
30 sers.

There are other examples of lasers of other wavelengths and materials for which the present invention is applicable. Generally, laser diode pump sources used in fiber amplifier applications are working in single transverse
5 mode for efficient coupling into single-mode fibers and are mostly multiple longitudinal mode lasers, i.e. Fabry-Perot (or FP) lasers. Three main types are typically being used for Erbium amplifiers, corresponding to the absorption wavelengths of Erbium: InGaAsP and multiquantum-well InGaAs lasers at 1480nm; strained quantum-well InGaAs lasers at 980nm; and GaAlAs lasers
10 at 820nm.

One of the problems occurring when using semiconductor lasers for the above purpose is their wavelength and power output instability which, though small, still affects the amplification sufficiently to look for a solution to the
15 problem. This problem is already addressed in Erdogan et al. US patent 5 563 732, entitled "Laser Pumping of Erbium Amplifier", which describes the stabilization of a pump laser of the type described above by use of a Bragg grating in front of the laser. This grating forms an external cavity with the laser. The laser bandwidth is broadened and stabilized by the reflection from
20 the grating. It is believed that the laser operation in so-called "coherence-collapse" is obtained by providing sufficient external optical feedback, here from a fiber Bragg grating within the optical fiber into which the laser light is usually coupled. This grating is formed inside the guided-mode region of the optical fiber at a certain distance from the laser. Such a fiber Bragg grating is
25 a periodic structure of refractive index variations in or near the guided-mode portion of the optical fiber, which variations are reflecting light of a certain wavelength propagating along the fiber. The grating's peak-reflectivities and reflection bandwidths determine the amount of light reflected back into the laser.

Ventrudo et al. US patent 5 715 263, entitled "Fibre-grating-stabilized Diode Laser" describes an essentially similar approach for providing a stabilized laser, showing a design by which the laser light is coupled to the fiber by focussing it through a fiber lens. Again, a fiber Bragg grating is provided in the
5 fiber's guided mode portion, reflecting part of the incoming light back through the lens to the laser. To summarize, when positioning a fiber Bragg grating beyond the coherence length of the laser and when the laser gain peak is not too far from the Bragg grating's center wavelength, it is understood that the laser in coherence collapse operation is forced to operate within the optical
10 bandwidth of the grating and thus is wavelength-stabilized. Additionally, low-frequency power fluctuations seem to decrease by the effect of induced high-frequency multi-mode operation.

In general, the above-described prior art devices must have a length of the
15 external cavity, i.e. the optical fiber, somewhere at least between 0.5 and 1m, to definitely assure coherence collapse laser operation. For some even up to 2m long optical fibers are required. This rather long fiber determines the size of the laser source and makes it comparatively bulky.

20 Some types of semiconductor lasers, especially others than those in the above mentioned patents, e.g. lasers having a narrow spectral gain width, are seen to exhibit instability at certain operating conditions, in particular undesirable switching from multi-mode to single-mode operation within the grating bandwidth. This mode switching (coherence collapse occurs in both cases)
25 results in a fluctuation of the effective laser output which in turn produces noise, thereby negatively affecting or actually disturbing the amplification process. The mode-switching problem is aggravated by new generations of semiconductor laser diodes having at least twice as much output power than the lasers in the Ventrudo or Erdogan patent and the desire of the industry to
30 have wavelength stabilization for all possible operating conditions of a laser.

Other techniques have been proposed to correct fiber amplifier output power fluctuations, e.g. active methods to control the variations in the fiber amplifier output by feedback of an electric signal effecting a correction of the laser power. A further solution is an electronic dithering circuitry forcing the laser to

5 operate multimode, described by Heidemann et al. in US patent 5 297 154, entitled "Fiber-Optic Amplifier with Feedback-Insensitive Pump Laser". However, the need for active components for these solutions add complexity and cost.

- 10 For a quite different purpose, Fischer et al. describe in "High-dimensional Chaotic Dynamics of an External Cavity Semiconductor Laser", Phys. Review Letters, Vol. 73, No. 16, October 1994, pp. 2188-2191, an experimental laser setup with an external T-shaped cavity comprising a beam splitter and high-reflecting gold mirrors at each of the two ends of the cavity's two arms.
- 15 Though this layout shows an external two-cavity arrangement, it is absolutely unsuitable for the purpose of the present invention, since the lengths chosen for the arms of the cavity and the reflectivities of the laser's exit facet and the above-mentioned gold mirrors are selected to avoid the coherence collapse - just the opposite of the present invention, where coherence collapse is a
- 20 prerequisite.

- Also in a very different field, Wang Xiangyang et al. disclose a "Theoretical and Experimental Study on the Fabrication of Double Fiber Bragg Gratings" in the journal Optical Fiber Technology: Materials, Devices and Systems, Vol. 3,
- 25 No. 2, pp.189-193. Double gratings are provided at the same location within the fiber and this "chirped" grating is said to widen the transmission spectrum of the fiber. Again, this publication does nowhere address the problem that the invention intends to solve.

- 30 Thus, it is the main object of the invention to devise a simple and reliable laser source layout, especially for pump lasers in optical fiber communication

- systems, that provides a stable output under all operating conditions. A specific object is to avoid the detrimental mode switching of the laser, even for a laser output power of more than 150 mW, and thus increase the stability of the output of high power laser sources. Output stability shall be achieved for
- 5 high optical power having reduced low frequency noise, wavelength stability and high side lobe suppression outside the fiber Bragg grating bandwidths.

A further object is to allow maximum flexibility for choosing the laser's parameters without running into stability problems.

10

A still further object is to avoid any further complexity and keep the number of additional components of the laser source within a laser pumped optical amplifier to a minimum.

- 15 A particular object is to create a stabilized laser source of reduced size by using a significantly shortened external cavity region.

The Invention

In brief, to solve the problems addressed above, the present invention does

20 not use a single grating or cavity in front of the laser, but a plurality of appropriately arranged cavities. These cavities are preferably arranged in series, but can also be arranged in parallel. If the lengths of the cavities, their reflectivities, and their peak wavelengths are chosen accordingly, the laser is forced to operate multimode under all or practically all operating conditions.

25

Whereas one single grating is known to act as a wavelength broadening and stabilization element, it is understood that multiple cavities according to the invention impose a useful destabilization only within the compound bandwidth of all gratings high enough to force the laser into multimode operation. In a

30 way, this phenomenon may be named as a "photonic dither" with a similar effect as an electronic dither, but by means of passive components only.

Another advantage of the invention is that the total length of the external cavities can be reduced to less than the length of the prior art designs. This provides for smaller laser sources.

5

One preferred embodiment according to the invention has a first reflector in front of a semiconductor laser diode forming a first cavity and, at an optimized distance, a second reflector in front of the first one, forming a second cavity between the first and the second reflector within the optical fiber. The peak
10 wavelength of the second reflector may be chosen close, but not necessarily identical to that of the first reflector. Also, a certain offset of the peak wavelengths and/or bandwidths of the two reflectors may improve performance. Further, any one or both cavities may be shorter than the coherence length of the laser diode.

15

Preferably, the phase relationship between the two reflectors is chosen such that the resulting waves or fields are - statistically seen - practically out of phase.

20 The reflectors can be of any kind suitable for the desired purpose; they are preferably provided as Bragg gratings within the optical fiber, which simplifies their making and avoids the need to have any parts or components added.

A preferred method for providing the desired plurality of cavities is to establish
25 them by simultaneously producing the desired Bragg gratings within the optical fiber. This keeps the additional efforts to fabricate the additional cavities at a minimum and, at the same time, provides for close tolerances of the desired layout.

Detailed Description of Preferred Embodiments

In the following, various embodiments of the invention shall be described by reference to the drawings, in which:

- 5 Fig. 1 shows the layout of a first embodiment using fiber Bragg gratings;
- Fig. 2 depicts the layout of a second embodiment using other reflectors instead;
- Fig. 3 shows a third embodiment with cavities on both ends of the laser;
- Fig. 4 is a fourth embodiment with frontal and lateral cavities;
- 10 Fig. 5 is a graph of a laser's optical bandwidth at -20 dB down from the maximum stabilized by a single fiber Bragg grating according to the prior art;
- Fig. 6 is a graph showing the improvement when a second cavity is implemented according to the invention (here using a second fiber
- 15 Fig. 6 Bragg grating).

- Fig. 1 shows the basic layout of a first embodiment according to the invention. A semiconductor diode laser 1, here an InGaAs quantum well laser, produces a laser light beam 3 that is emitted predominantly from the laser front facet 2.
- 20 This beam is coupled into a suitable optical fiber 5 via a fiberlens 4, focusing the beam onto the input end of the fiber 5. Within the optical fiber 5, a first fiber Bragg grating 6a is arranged in a distance L1 from the laser 1. In a distance L2 from this first grating 6a, a second fiber Bragg grating 6b is provided. The controlled and now incoherent - as described above - exiting light
- 25 beam 7 leaves the optical fiber 5 and is fed into a fiber amplifier, e.g. an Erbium-doped fiber amplifier not shown here.

- The semiconductor laser is usually of a type that emits confined light in a single transversal and lateral mode, but has several longitudinal modes due to
- 30 the Fabry-Perot cavity formed between the front and rear facet. If the laser facet reflectivity has a value as low as 10^{-5} , the laser cavity extends essen-

- tially into the fiber with the fiber Bragg grating defining the end facet. In this case, the laser operates more likely in coherence with the fiber Bragg grating. Thus, a higher front facet reflectivity of the laser typically on the order of 4% is desired to ensure coherence-collapse. On the other hand, if the reflectivity is
- 5 chosen too high, the optical output power is decreased. The efficiency of the light coupled from the laser into the fiber through the fiber lens can be about 70% in production and approaching 85% in the lab and/or for specially designed lasers. Hence, the efficiency of fiber Bragg grating back reflection into the laser is then given by the squared coupling efficiency times the Bragg
- 10 grating reflectivity. Typically, more than 90% of the light passes the Bragg grating whereas the rest is reflected back into the laser, if it is the first grating, or passing through another fiber Bragg grating with a part of it reflected back again.
- 15 If the wavelength of the free-running laser without backreflection, roughly corresponding to the laser gain peak, is too far from the fiber Bragg grating peak, the laser may fall off the locking to the Bragg grating. A 20nm wavelength range can be typically locked to the fiber Bragg grating peak, denoted as the so called capture range. The grating bandwidth is determined by the
- 20 needs for pump wavelength channel separation in EDFAs with a typical maximum limit of 2nm. From a manufacturing viewpoint, the full-width half-maximum bandwidths can be chosen between 0.4 and 0.8nm for a certain peak reflectivity. A laser-to-grating distance of $> 50\text{cm}$ ensures coherence collapse, but this distance can be smaller if several gratings (cavities) are
- 25 used. The well known fiber Bragg grating fabrication is based on exposure to UV radiation periodically along a piece of the optical fiber, as described e.g. by Raman Kashyap in "Fiber Bragg Gratings", Academic Press, 1999.
- The reflectivity of the multiple gratings is an optimization versus output power.
- 30 The effective, or compound reflectivity given by all gratings can be in the same range as the laser facet reflectivity. A wavelength overlap is also nec-

essary to establish another cavity. A concrete example with two gratings, each with 3% reflectivity, (i.e. $2 \times 3\%$ reflectivity) and 0.6nm bandwidth at the same peak wavelength gives excellent results. The function of having multiple cavities is given by the roundtrip time the portion of the backreflected light
5 needs to get back into the laser cavity. It can be seen as a "photonic dither" with frequencies corresponding to the roundtrip times through the various cavities. A working example has a laser-grating distance L1 of 1m and a grating-grating distance L2 of 10cm, yielding roundtrip frequencies of 100MHz and 1GHz, respectively. Distortions at different frequencies determined by
10 the roundtrip time (length) of the multiple cavities forces the laser to become multimode. The light leaving the last fiber Bragg grating entering the path to the EDFA shows minimal low frequency noise with typically 90% of the light confined to the bandwidth determined by the grating. Some noise at high frequencies exists due to mode beating, but does not interfere with the slowly
15 reacting ions of the subsequent Erbium-doped amplifier.

A different method to get distortion by light reflected back into the laser is to have different grating wavelengths, where the first grating acts as the master grating, locking the pump wavelength, and the second grating, with a lower
20 reflectivity, acts as a noise-producing element.

Fig. 2 shows a second embodiment, essentially an arrangement wherein the fiber Bragg gratings 6a and 6b of Fig. 1 have been replaced by reflectors 16a and 16b, which may be e.g. a set of interferometric filters. This set of filters
25 has essentially the same function as Bragg gratings with similar reflection and transmission characteristics. They can either be discrete elements between the fibers (as shown in Fig. 2) or can be deposited directly onto the fiber. Also, the fiberlens 4 has been replaced by another collimating means, here a lens system 14. The optical fiber is partitioned into three sections 15a, 15b,
30 and 15c. The light beam 7 exits from the last section of the optical fiber 15c, as in Fig. 1. Regarding the dimensions in this second embodiment, the same

rules and calculations as described above in connection with the embodiment of Fig. 1 apply.

There is no rear reflector shown at the laser 1 in both Figs. 1 and 2, but it is
5 clear for a person skilled in the art that such a reflector or mirror is usually provided.

Fig. 3 depicts a layout with cavities both in front of the laser and at the rear of it. Whereas cavities 5a and 5b are located essentially similar to the embodiment shown in Fig. 1, some light exits the laser 1 through its rear facet 22,
10 entering, preferably through a fiberlens 24, the two rear cavities 25a and 25b, established by a fiber Bragg grating 26a and a rear fiber reflector 26b. The reflectivity at the rear laser facet and/or the compound reflectivity of all rear gratings should be higher than 90%, preferably 100% to maximize the output
15 power at the laser's front facet. Again, the rules and calculations described above in connection with Fig. 1 apply with respect to the dimensions and reflectivities in this third embodiment.

Fig. 4 displays a fourth embodiment of the invention with "parallel" cavities
20 instead of a series of cavities, here a "frontal" cavity 15a and a "lateral" cavity 33. This embodiment is shown to explain how the functionality of the invention can be achieved by a quasi-parallel instead of a serial setup of feedback cavities. A beam splitter/combiner 31 divides the laser beam, where typically more than 90% of the laser light is coupled out into the fiber 15c to exit the
25 system, whereas a certain portion is reflected into the fiber 15a acting as first cavity. A smaller portion of the laser light is deflected into the cavity 33 and therein backreflected at the mirror 34. This mirror 34 ideally has a reflectivity of 100%, the same as the rear laser reflector 32. The roundtrip frequency is again determined by the lengths of the cavities, working as the necessary
30 distortion elements leading the laser 1 to multimode operation.

The layout shown in Fig. 4 may be modified by adding a further cavity right of the beam splitter/combiner 31 similar to the two-cavity layout of Fig. 2. Another modification of the layout of Fig. 4 could add one or more rear cavities similar to the layout shown in Fig. 3. To summarize, based on the teaching

5 given and without departing from the spirit and scope of the invention, it should be relatively easy for a person skilled in the art to combine any of the designs shown, or to add portions of one design to another, and to determine the dimensions according to the teaching given particularly in connection with Fig. 1.

10

Fig. 5 shows in graphical form the output of a laser known from the prior art, whereby the bandwidth stabilization is attempted by a single fiber Bragg grating. The vertical axis is the laser's optical bandwidth at -20 dB down from the maximum; the horizontal axis is the laser current. The graph clearly shows

15 the fluctuations by the laser's switching from multi-mode bandwidth (a) to narrow single mode (b) operation or bandwidth while the laser's driving current is ramped up. In other words, the shown curve exhibits just the problem that the present invention intends to solve.

20 Fig. 6 finally exhibits the progress achieved by the present invention in a graph similar to the one in Fig. 5. Again, the vertical axis is the laser's optical bandwidth at -20 dB down from the maximum; the horizontal axis is the current of a laser source according to the invention. By use of an additional cavity formed by a second grating or other reflector system, e.g. as described

25 in detail in connection with Fig. 1, the laser source is solely operating in multi-mode. There are no switching fluctuations, the significant improvement is clearly visible.

Claims

1. A laser source for generating a stable laser beam of a given bandwidth,
5 including a laser (1) and guide means (5) for conducting the laser beam exiting said front facet, characterized by
 - a plurality of external cavities (5a, 5b; 15a, 15b; 25a, 25b; 33) at least partly within or as part of said laser beam guide means (5), each of said cavities being established by at least two reflectors (2 and 6a, 6a and 6b;
10 2 and 16a, 16a and 16b; 2 and 26a, 26a and 26b; 2 and 31, 31 and 34),
 - said plurality of external cavities being dimensioned and arranged such that said laser (1) operates essentially in a coherence collapse mode.
2. The laser source according to claim 1, wherein
15 - all cavities (5a, 5b; 15a, 15b) are situated within the laser beam guide means (5), preferably in front of the laser (1).
3. The laser source according to claim 1, wherein
 - one or more cavities (5a, 5b) are arranged within the laser beam guide means (5) in front of the laser (1), and
20 - at least one cavity (25a, 25b) is arranged at the rear of the laser (1).
4. The laser source according to claim 1 or 3, including in combination
 - a "serial" cavity (15a) arranged within the laser beam guide means (5),
25 - a "lateral" cavity (33) arranged outside said laser beam guide means (5), and
 - a beam splitter/combiner (31) deflecting a portion of the beam into said lateral cavity.

5. The laser source according to one or more of the preceding claims, wherein
- two reflectors, in particular Bragg gratings, are provided, whose peak wavelengths are offset and/or bandwidths are different.
- 5
6. The laser source according to one or more of the preceding claims, wherein
- the laser (1) emits light between 800 and 1600nm and/or
 - any of the reflectors (6a, 6b; 16a, 16b; 26a, 26b; 34) or beam split-
 - 10 ters/combiners (31) has a reflectivity maximum within the bandwidth of the laser, and/or
 - a bandwidth of its reflectivity between 0.05 and 2nm full-width half-maximum, and/or
 - a peak reflectivity between 0.005 and 0.4.
- 15
7. The laser source according to one or more of the preceding claims, wherein
- the optical field established in the first cavity (5a, 15a, 25a) is out of phase with the optical field of the laser (1), and
 - 20 - the optical field established in the second cavity (5b, 15b, 25b, 33) is out of phase with the optical field established in said first cavity,
 - thus inhibiting phase matching with the laser and hence coherent operation of said laser source.
- 25
8. The laser source according to one or more of the preceding claims, wherein
- the laser is a semiconductor diode laser, especially an InGaAs quantum well diode laser, and/or
 - the laser guide means comprises an optical fiber, either a polarization-
 - 30 maintaining or non-polarization maintaining optical fiber, and/or
 - the reflectors are fiber Bragg gratings within said fiber.

9. The laser source according to one or more of the preceding claims, further comprising

- means for directing the laser beam into the optical fiber, in particular beam collimating or focusing means (4, 14) attached to or integrated into said optical fiber (5).

10. A method of making a laser source that generates a stable laser beam of a given bandwidth, said laser source having a laser (1) and laser beam guide

means (5) in front of said laser, characterized by

- simultaneously manufacturing, preferably within said laser beam guide means (5), a plurality of reflectors (6a, 6b), which form, together with the laser front facet (2), the desired external cavities (5a, 5b) in front of said laser (1).

11. The method of making a laser source according to claim 10, whereby

- the simultaneous manufacturing is carried out by UV exposure methods creating the reflectors (6a, 6b) as fiber Bragg gratings in the optical fiber constituting the laser beam guide means (5).

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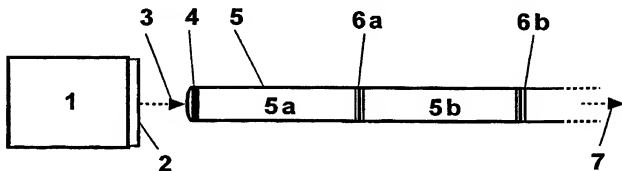
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(54) Title: STABILIZED LASER SOURCE



(57) Abstract: The invention relates to the stabilization of semiconductor laser diode sources as they are extensively used in the field of optical communication. Such lasers are mostly employed as so-called pump laser sources for fiber amplifiers, e.g. Erbium-doped fiber amplifiers, and are designed to provide a narrow-bandwidth optical radiation with a stable power output in a given frequency band. To improve the stability of such laser sources compared to prior art designs, a plurality of "external" cavities is provided. In the commonly employed optical fibers for conducting the laser beam, these cavities may be formed by a plurality of appropriately designed Bragg gratings. However, the cavities may as well be formed by other means reflecting a given amount of the energy back to the laser in a desired frequency band, thus effecting the desired stabilization of the laser's intensity and frequency.

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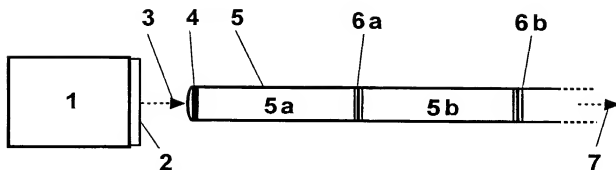


Fig. 1

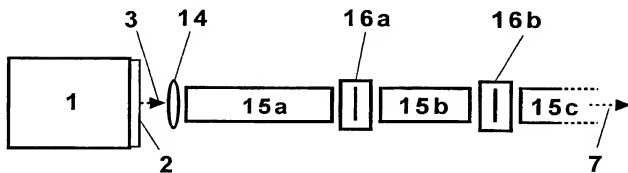


Fig. 2

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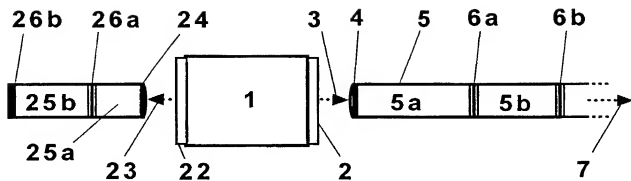


Fig. 3

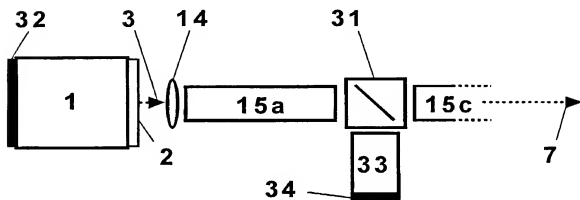


Fig. 4

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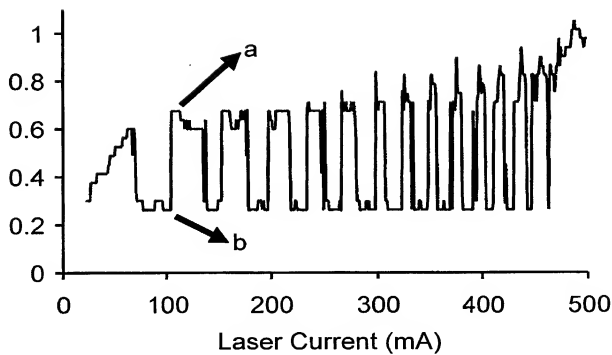


Fig. 5

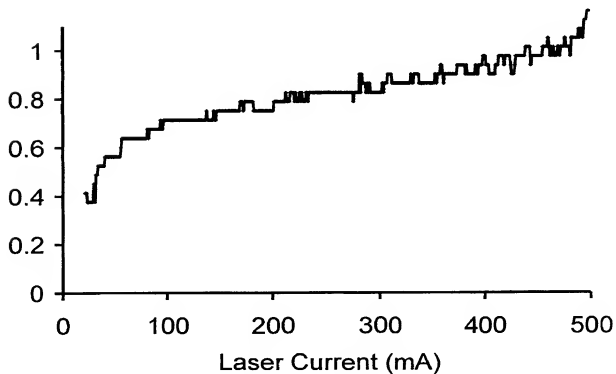


Fig. 6



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DECLARATION AND POWER OF ATTORNEY FOR PATENT APPLICATION

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled **STABILIZED LASER SOURCE**, the specification of which:

- ☐ is attached hereto.
- ☒ was filed on **September 1, 2000** as

PCT Application Serial No. **PCT/IB00/01237**

and was amended on **February 13, 2002** (if applicable).

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, Section 1.56(a).

I hereby claim foreign priority benefits under Title 35, United States Code, Section 119 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

PRIOR FOREIGN APPLICATION(S)

<u>Country</u>	<u>Number</u>	<u>Date Filed</u>	<u>Priority Claimed</u>	
			<u>Yes</u>	<u>No</u>
<u>EPO</u>	<u>99810837.7</u>	<u>September 21, 1999</u>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
_____	_____	_____	<input type="checkbox"/>	<input type="checkbox"/>

I hereby claim the benefit under Title 35, United States Code Section 120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, Section 112, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, Section 1.56(a) which occurred between the filing date of the prior application and the national or PCT international filing date of this application.

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(12) And I hereby appoint Thomas E. Smith, Registration No. 18,243, Dennis M. McWilliams, Registration No. 25,195, James R. Sweeney, Registration No. 18,721, William M. Lee, Jr., Registration No. 26,935, Glenn W. Ohlson, Registration No. 28,455, David C. Brezina, Registration No. 34,128, Jeffrey R. Gray, Registration No. 33,391, Timothy J. Engling, Registration No. 39,970, Gregory B. Beggs, Registration No. 19,286, Gerald S. Geren, Registration No. 24,528, Peter J. Shakula, Registration No. 40,808, and Robert F.I. Conte, Registration No. 20,354, to prosecute this application and to transact all business in the Patent and Trademark Office connected herewith. It is requested that all communications be directed to Lee, Mann, Smith, McWilliams, Sweeney & Ohlson, P.O. Box 2786, Chicago, Illinois 60690-2786, telephone number (312) 368-1300.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

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